Ac Losses in Coated Conductors

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Presentation Message

- Intended Message
  - The ac losses of coated conductors (CC) present a serious problem for applications.
    - “global” losses >>> economics
    - Quenching
  - Present research directions (“higher I_c and/or J_c”) will not solve this problem

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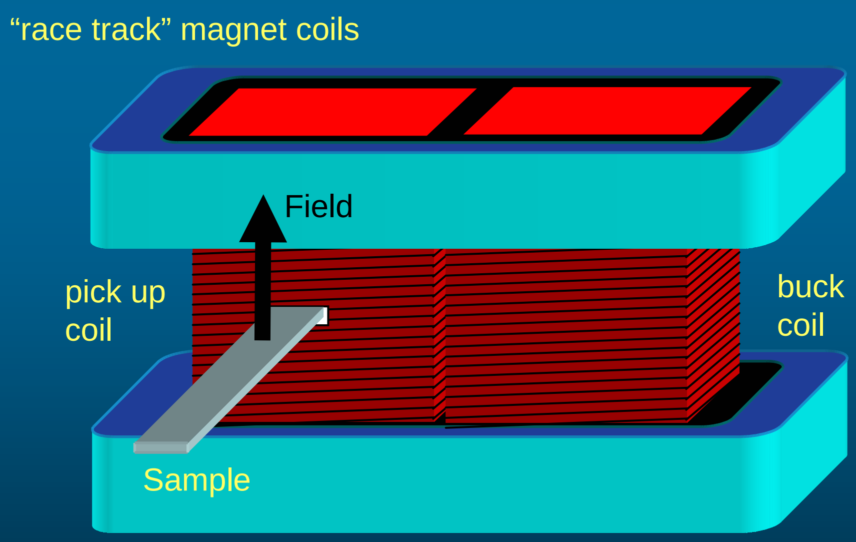
Presentation Outline

Outline

- Advances in loss measurement techniques
- Data on ‘standard’ CC
  - What we have and what is needed
- Data/Models for increased J_C or reduced width CC
  - Each is not enough, together may be
- Data on Filamentary CC
  - Not the solution
- Some ideas to reduce losses
  - No solution as yet though
- Continuous measurement of losses on long samples
- Quench studies
- Plans/Performance/Goals

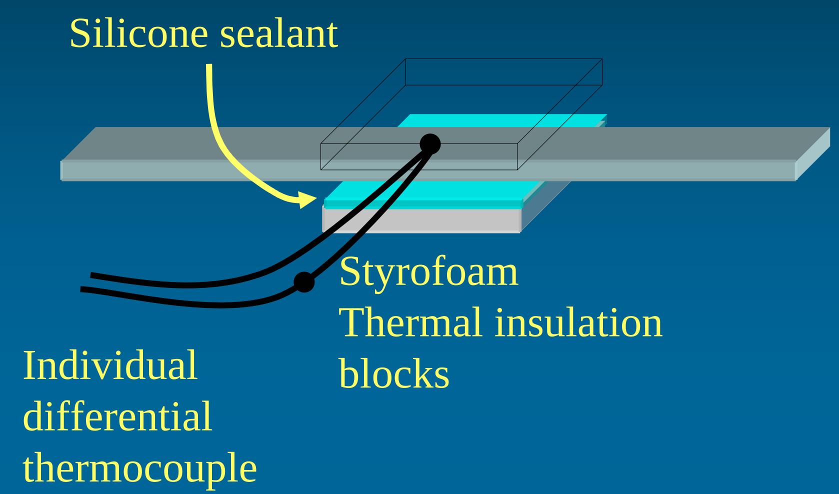
Measurment Techniques: Losses due to Magnetic Fields

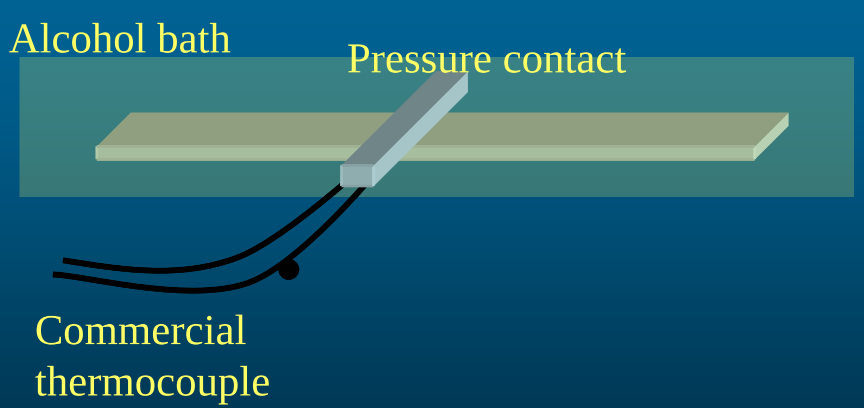
- Sample extend beyond end of magnet coils
  - Flux cannot enter from ends of sample
- Pick up coils extend above, to the side of sample
  - Capture all “loss” signal
  - System does not need calibrating
- Also extended to continuous measurement on 5m samples



Measurement Techniques: Losses due to Magnetic Fields AND Transport Currents

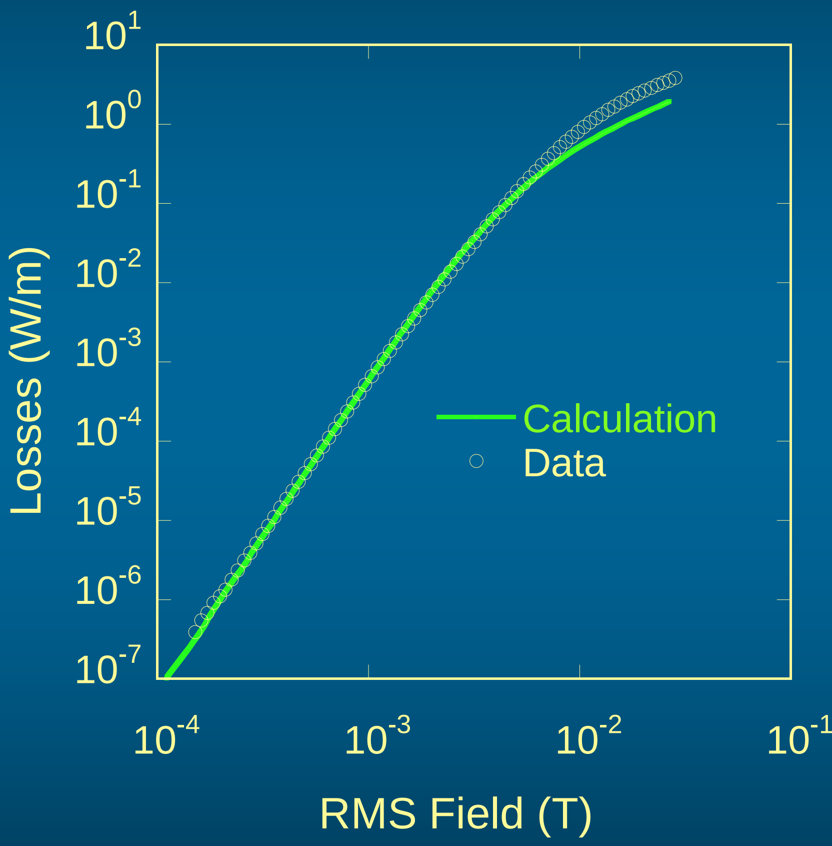
- Aim
  - Reduce sample change time from 1 day to 1 hour
  - Recover samples after measure
- How
  - Commercial thermocouple
  - Pressure contact not adhesive
  - No fixed thermal insulation
  - Frozen alcohol bath
    - Evaporates after use
- Reduced sensitivity but adaquate for these purposes





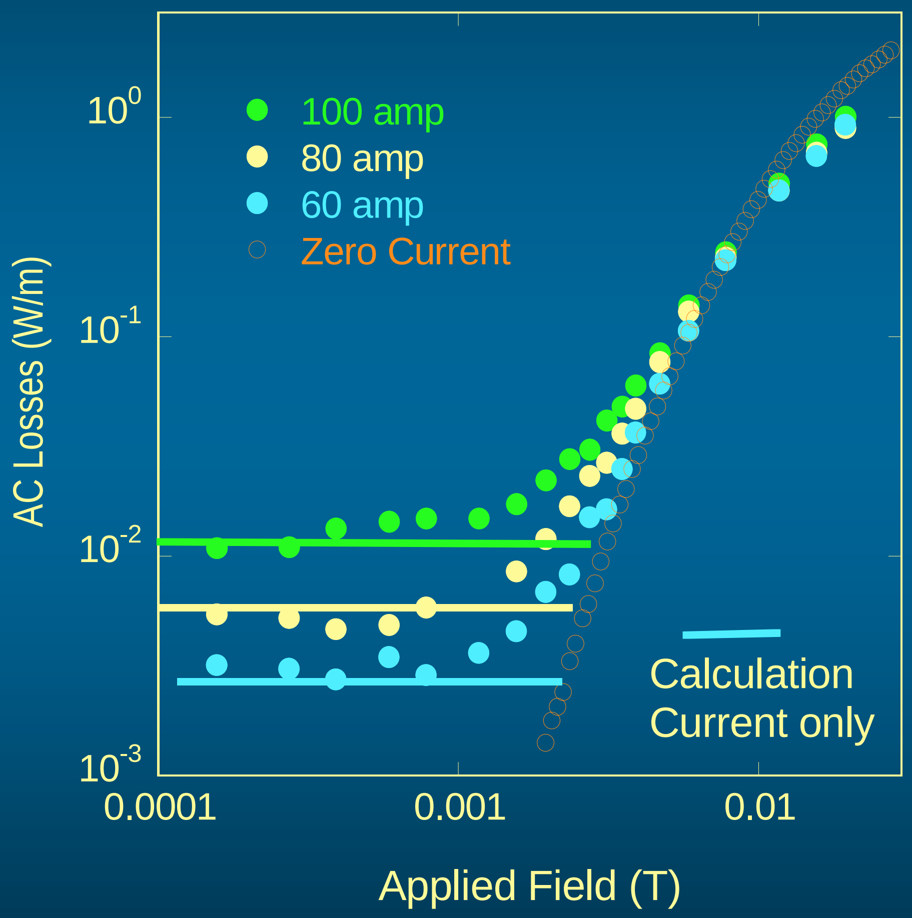
Results: Magnetic AC Losses

- High sensitivity
- Agrees well with 'Brandt' calculations for strips in field
  - No adjustable parameters
- 10mm wide IBAD CC
  - Perpendicular Field
  - 100A critical current
  - J_C = 1MA/cm^2
  - 60Hz data, 75K
- Note "full" penetration at 10mT
- Feature of '2D' system
  - Aspect ratio 10^4:1



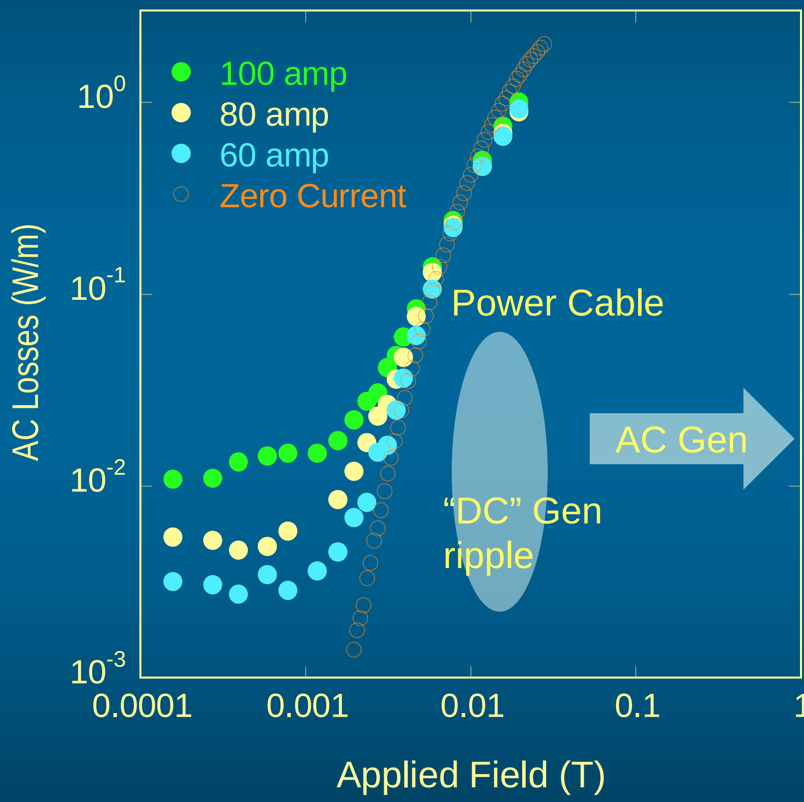
Results: Calorimetric Losses

- Lower sensitivity
- Slower measurement
- Allows current + field
- 10mm wide IBAD CC
  - 100A critical current
  - $J_C = 1 MA/cm^2$
  - 60Hz data, 75K
- Good approximation Loss=
  - Current loss +
  - Field loss
- Note above 5mT, losses are field dominated



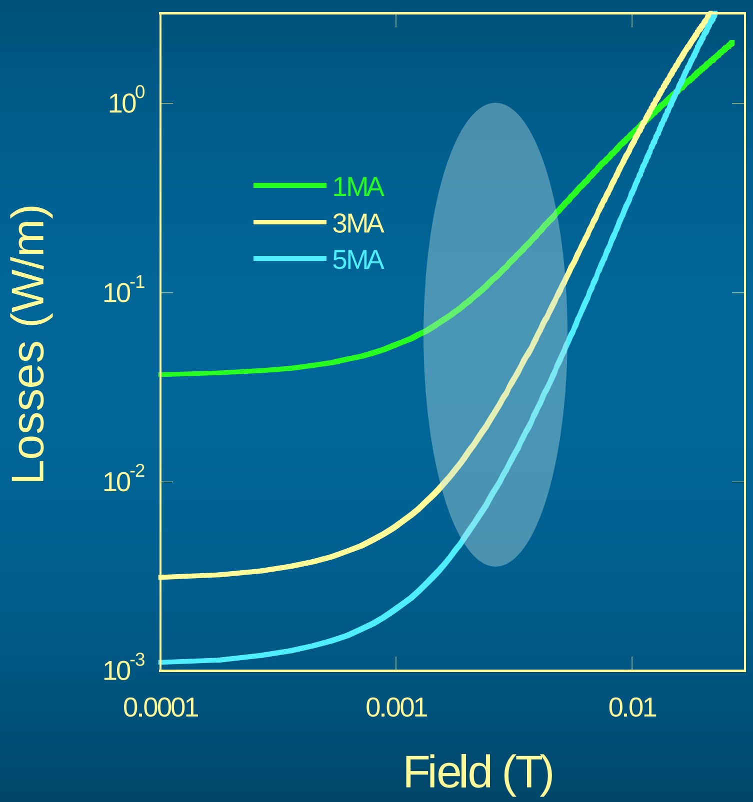
ac Losses: The Problem

- For applications
  - Power cable
    - ac field 20mT
  - “DC” generator/motor
    - Ripple 20mT+
  - Transformer
    - ac field >0.1T
  - ac gen..
    - Ac field 1T?
- Losses way too high for economy
- Bigger problem
  - Quenching (see later)



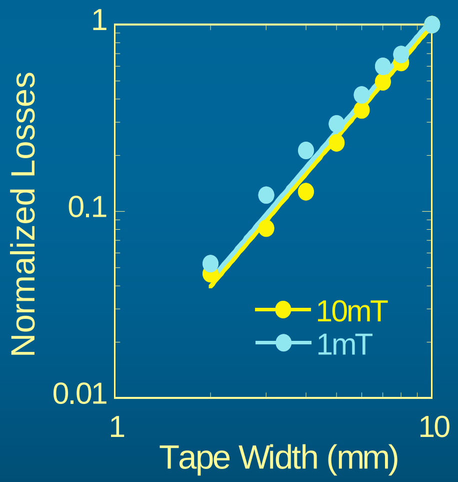
Model: What happens if we increase J_C?

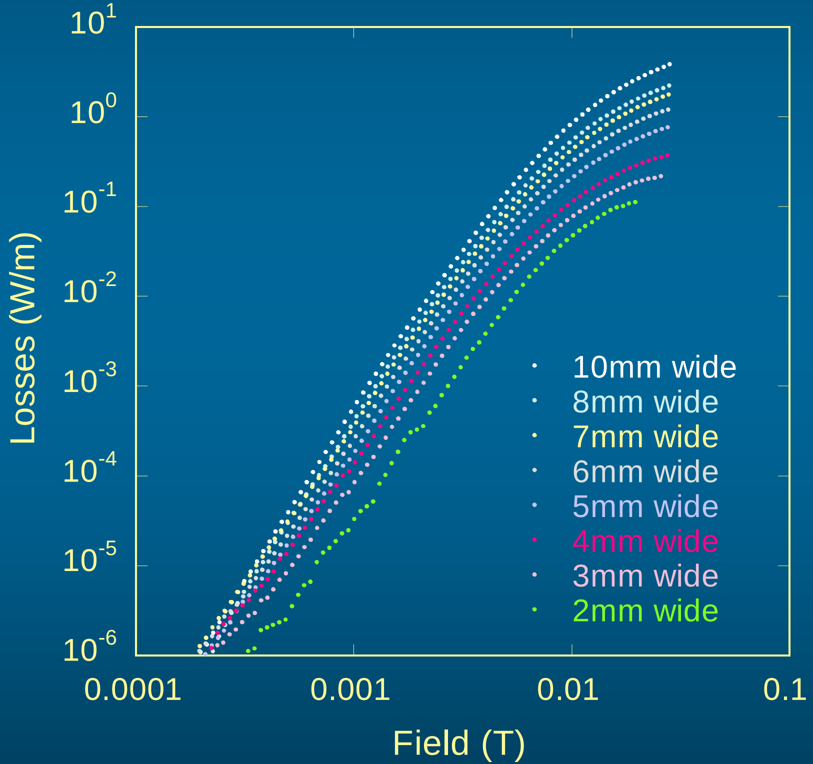
- Calculation
  - 10mm wide
  - Carrying 80A (80% of I_C for 1MA/cm^2)
  - Brandt theory for losses in strip
- "transport" (low field) losses reduce significantly
- Field dominated losses (>3mT) don't reduce as much
- This isn't going to be the whole solution
- Good news: higher J_C takes away the need to **transpose** if we make filaments



Data: Reducing tape width reduces losses

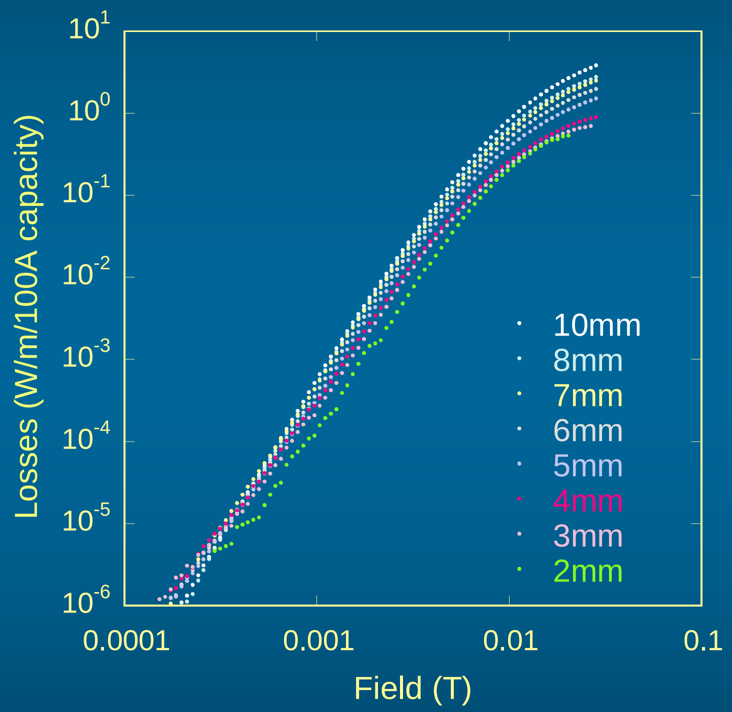
- Concentrate on magnetic field dominated region
- Losses at any given field reduce
- Square law





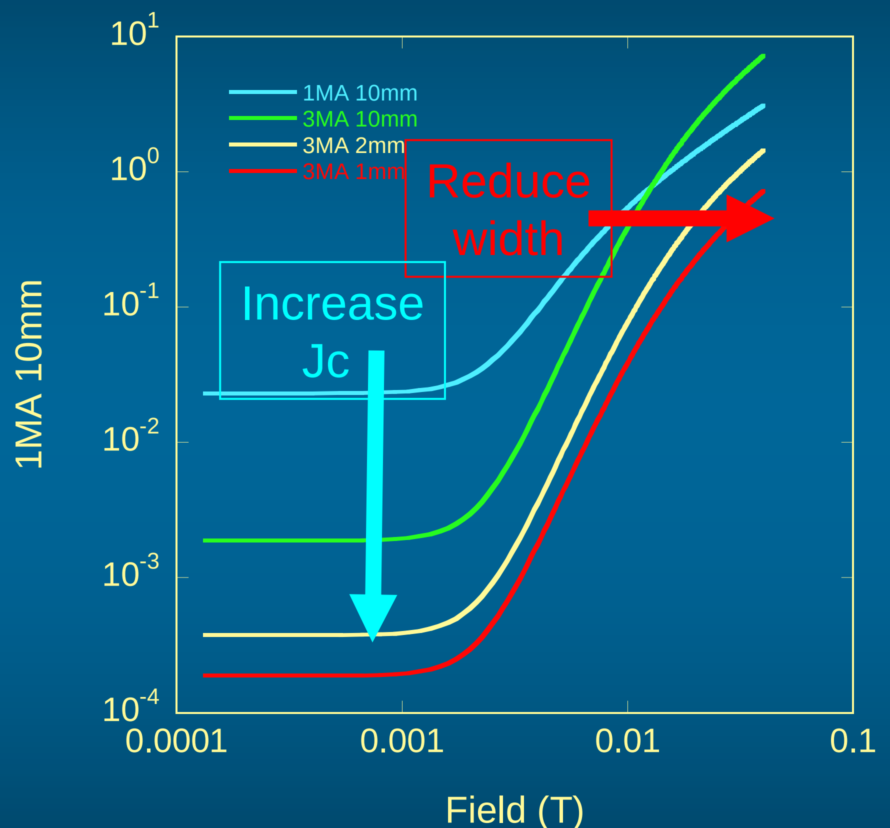
Changing width: not quite as good as it seems

- To carry a required current
- Reducing width >> more tape eg
  - 1 x 10mm tape
  - 10 x 1mm tape
- How do losses scale for fixed current carrying capacity?
- Losses now reduce linearly with width



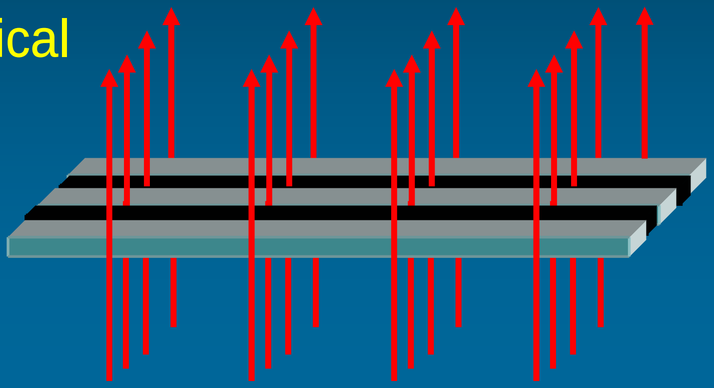
Model: Change Jc and width the answer?

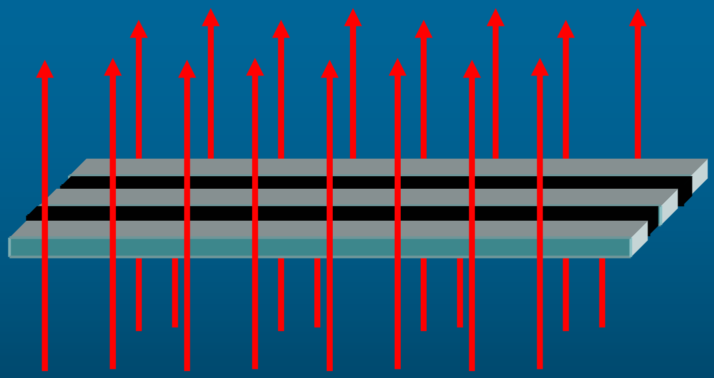
- Increasing Jc
  - decreases “transport” losses (<3mT)
- Reducing width
  - decreases “magnetic” losses
  - Moves field dominated region to right
- Still not getting to 0.1T region fro 1mm tape
- 0.1W/m still too high
- Reduce width further > filaments



Do filaments reduce losses?

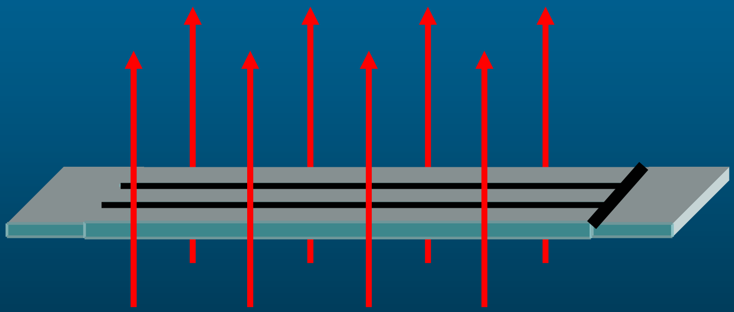
- Reduce effective width
- Only works if all filaments see identical fields
- Short samples OK
  - Field comes in from ‘ends’
- If sample is long, doesn’t work
- Field cannot get into space between HTS during ac cycle
- Usual solution is to ‘twist’
  - Not easy in tapes
  - Effective J_C reduces

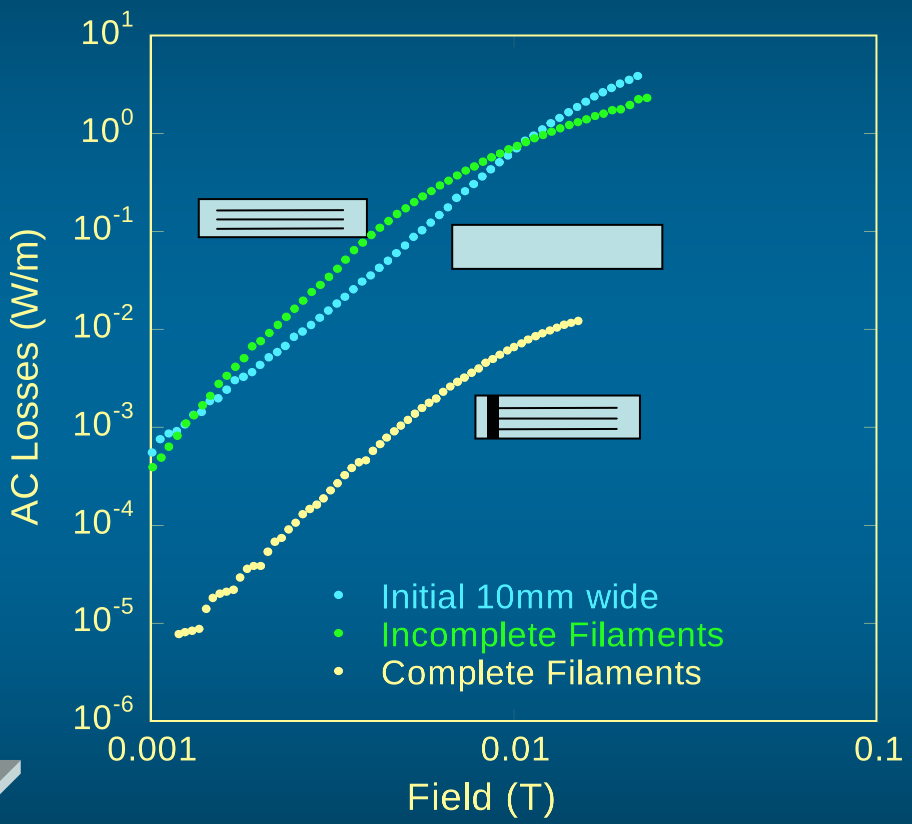




Data: Filaments alone do not reduce losses in long samples

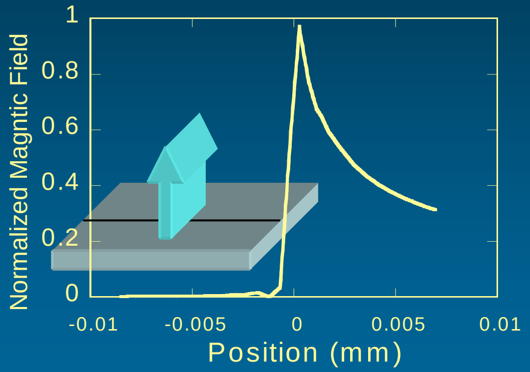
- IGC samples
- Simulate long samples with ‘incomplete’ filaments
- HTS ‘blocks’ flux entry from ends of sample
- Filaments do not reduce losses
- After measurement cut ‘block’
- Losses reduce
- Reduced loss from filaments alone is ‘experimental’ artifact

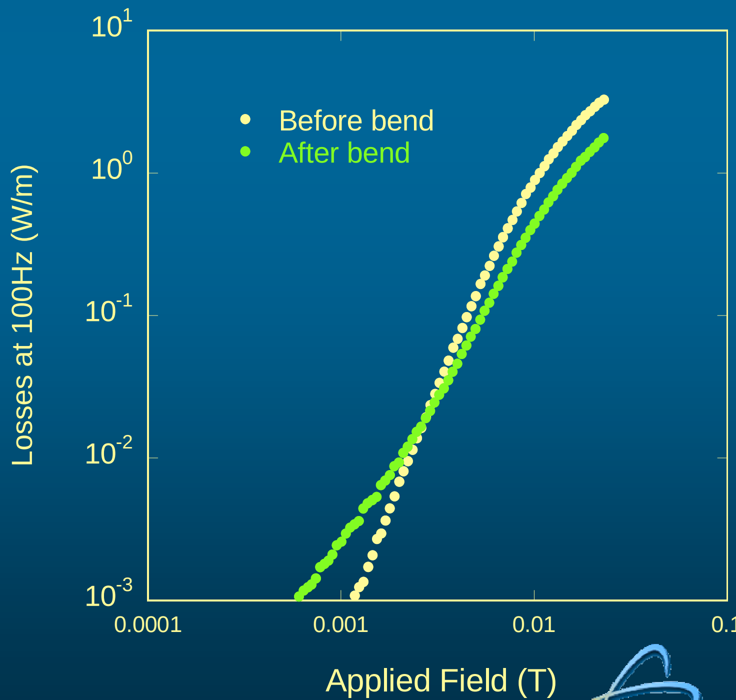




Other ways of reducing ac loss? Shaping samples

- Can we get away from “2D”
  - Very high fields at the tape edge
  - Bend edges to reduce perpendicular field
- Reduces losses at high field
- Increases at low field
- Reduction isn’t any more than simply reducing tape width





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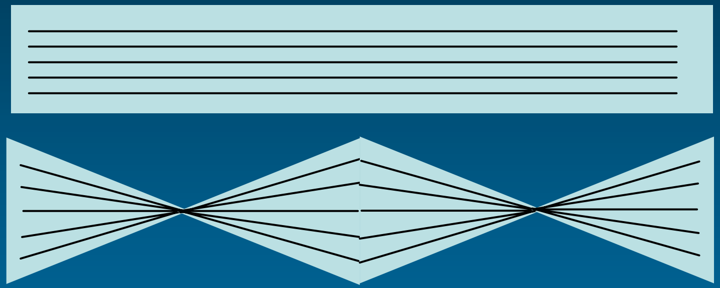
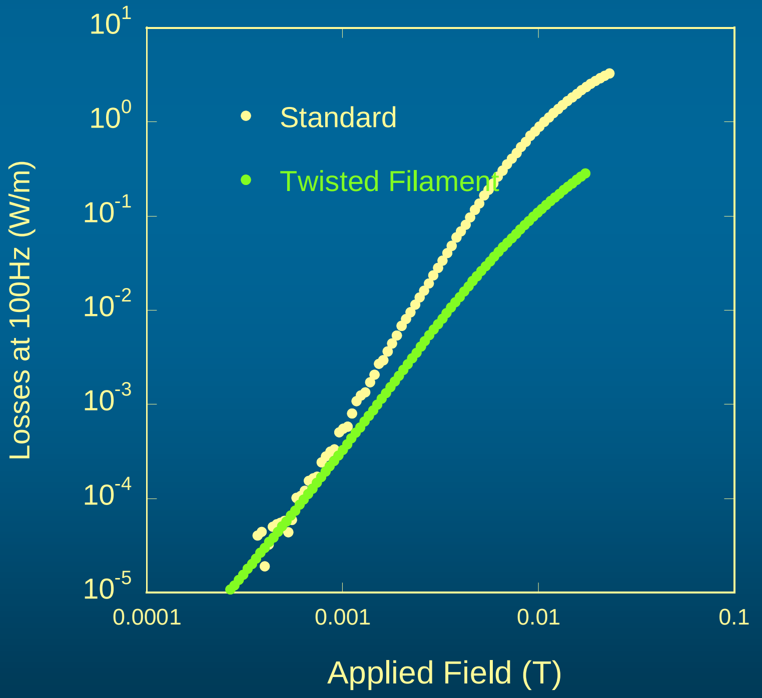
Other ways of reducing losses: twist

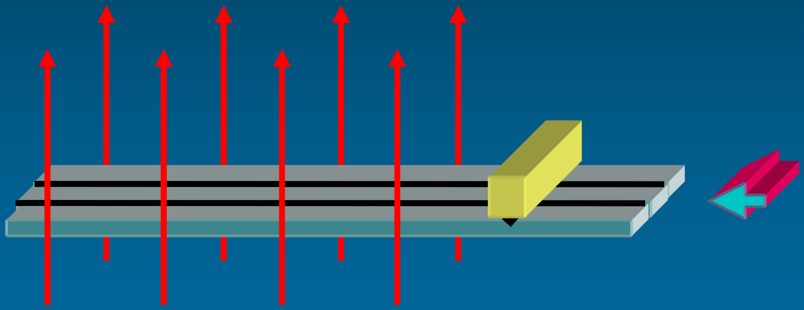
- Twisted filaments
  - 10mm wide tape
  - Cut to 5 filaments
  - Cut through substrate also
  - Twist to complete pitch
- Loss reduced at high field
- Engineering current density significantly reduced
- Proof of principle
- Not a practical method

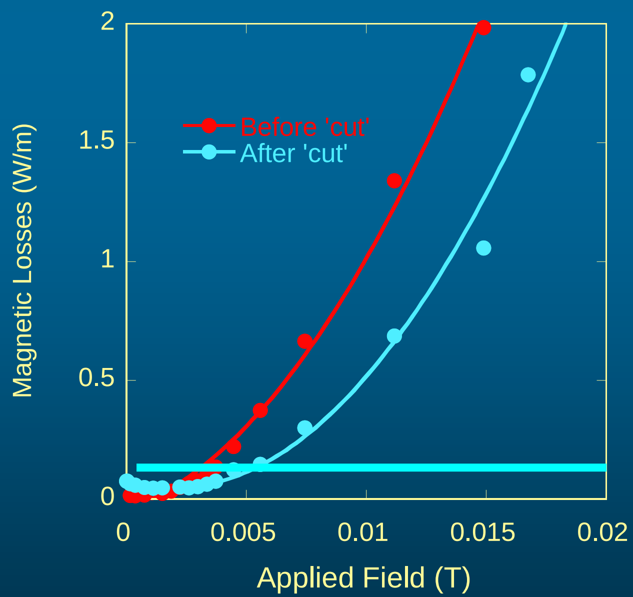




Reduce losses: Filaments and Bridges

- Filaments reduce losses if field can move between them
  - OK on short samples
  - Not on long samples
- “Cut” allows field to move into filaments
  - But stops transport current
- “Bridge” cut with eg copper
- Reduce magnetic losses
  - 80A transport current
  - 1W/m reduced to 0.5W/m at 10mT
- Increase “resistive” losses
  - Extra 0.05W per “bridge”
- Bridges 1um wide...0.01W?



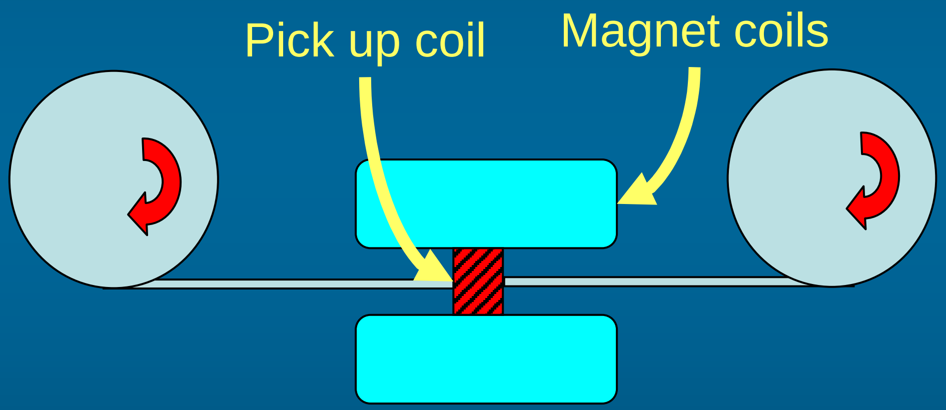


Conclusions: AC Losses

- ‘Loss Measurement techniques
  - Adequate for purposes now
- ‘Standard’ CC
  - Not good enough
- Increased J_C or reduced width CC
  - Each is not enough, together may be
- Filamentary CC
  - Be careful with measurements
  - Not the solution
- Ideas to reduce losses
  - Some good possibilities
  - No solution as yet though

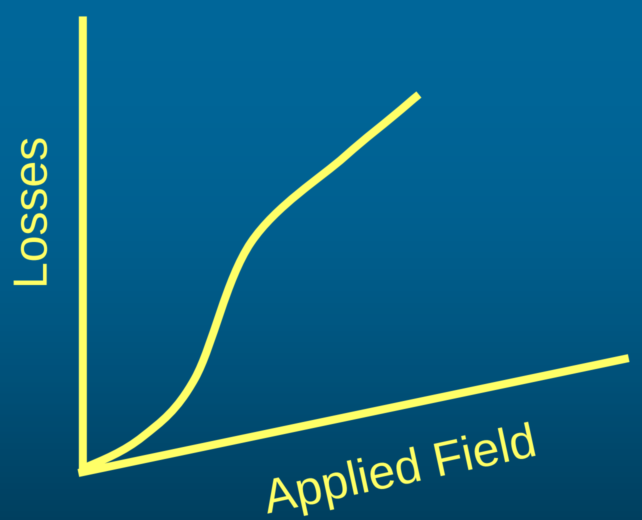
Reel to Reel AC Loss Measurements

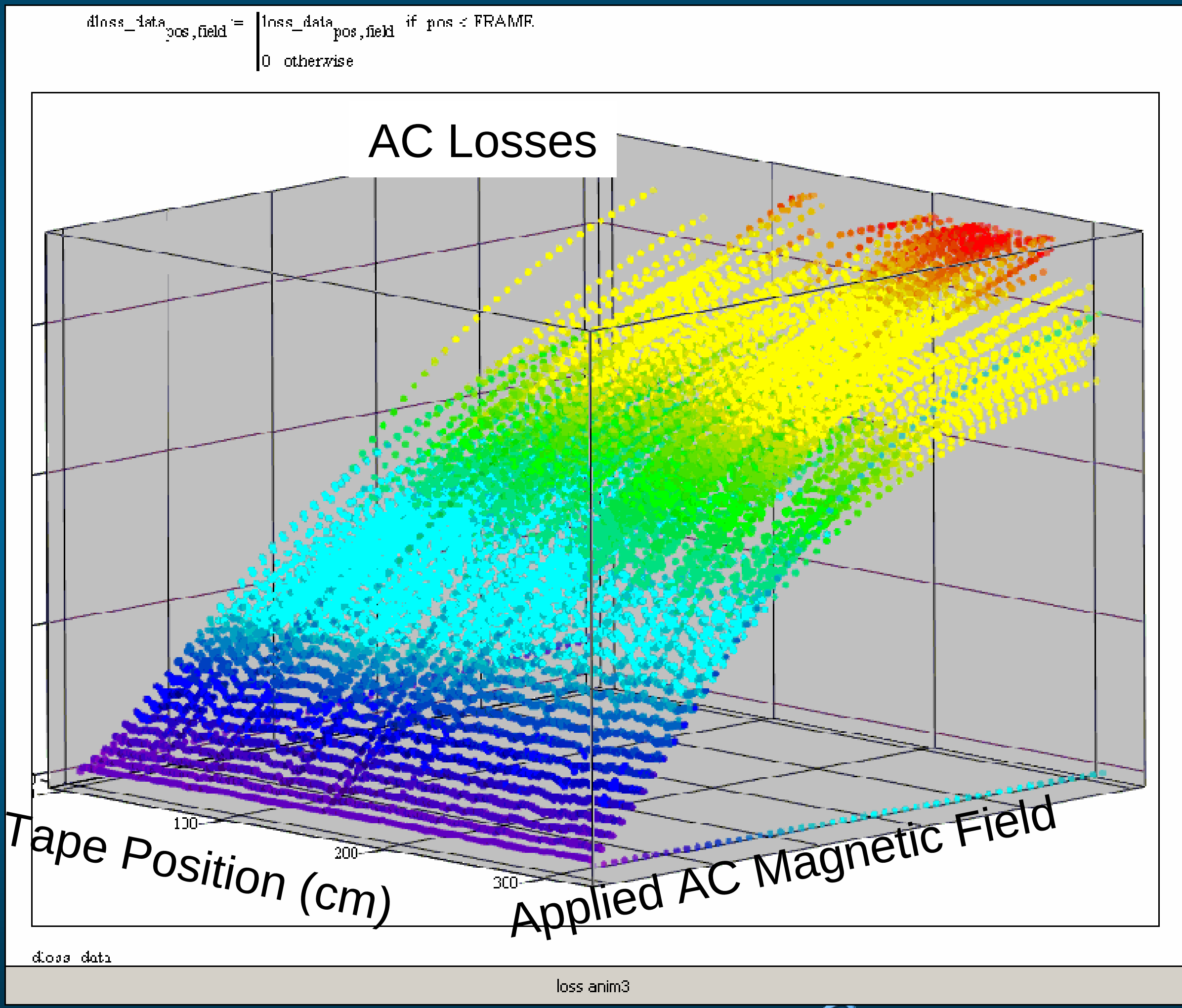
- ac loss can
  - probe across width of sample
  - Local J_C
- Measure every 1cm
- Measurement length 1cm
- Sweep ac field
  - 1mT to 25mT



Reel to Reel AC Loss Measurements : Data

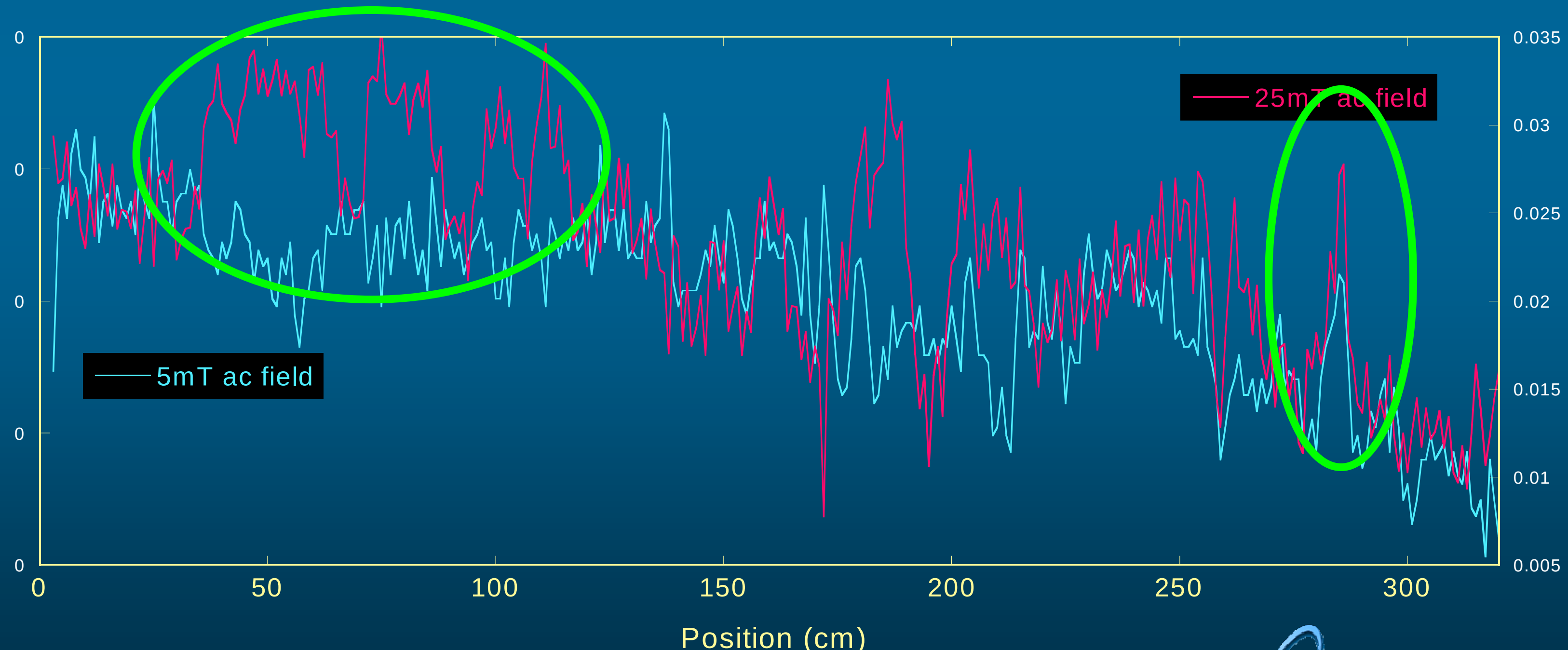
- 3.2m sample
- 10mm wide
- 75K
- Ic vary between 20A and 100A





Moving ac Loss Measurements: Compare high and low field losses

- Low field: loss inversely proportional to J_C
- High field: loss increases with increasing J_C
- Interpretation needs more work and comparing with local I_C
  - $I_C$varied on mm scale
  - How to compare with losses measured on cm scale



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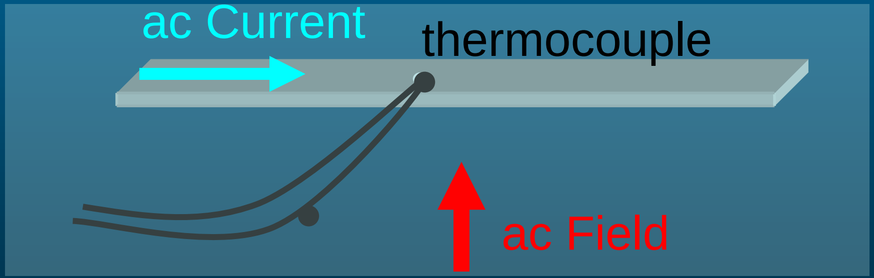
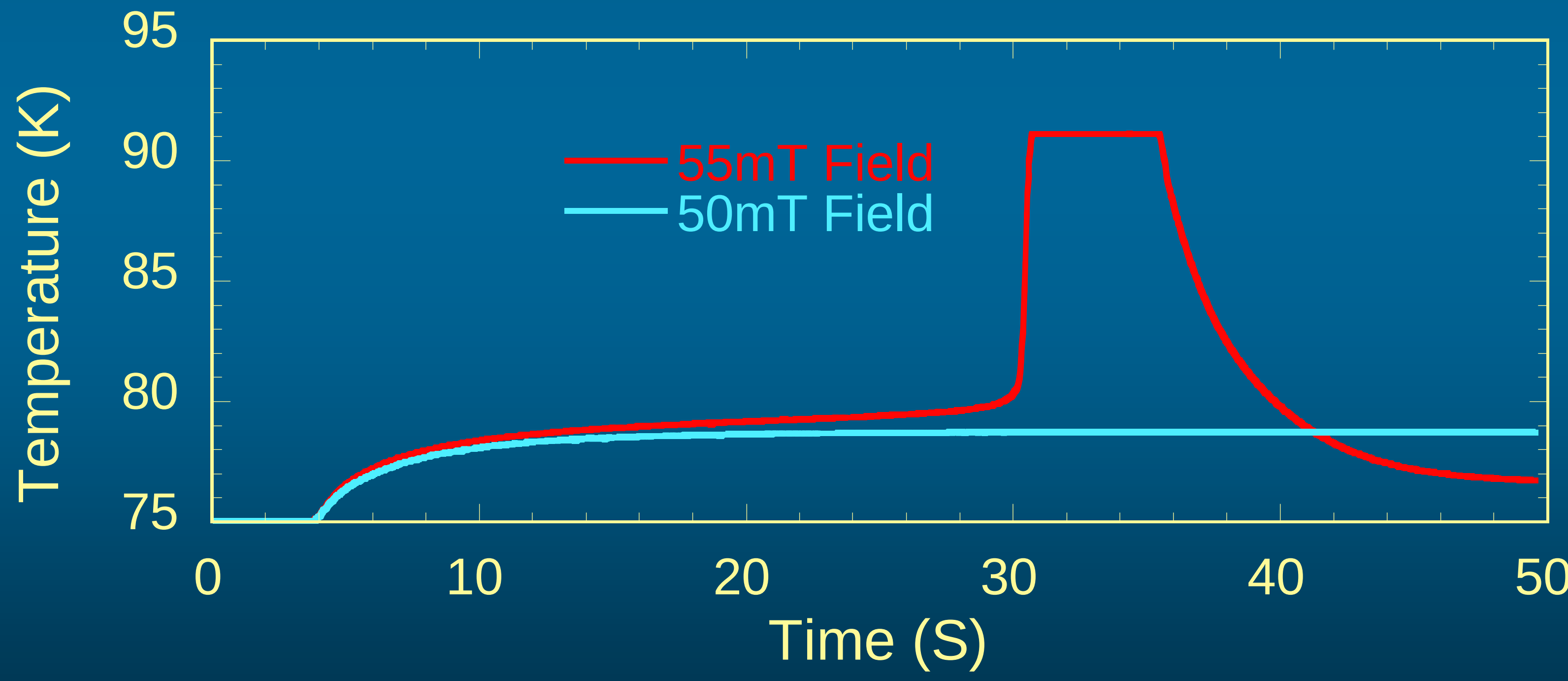
ac Loss Simulated Quenching

- Basic Questions
  - Can ac losses stimulate a quench?
  - Where is boundary between stable and quench regimes
- Experiment
  - Apply ac current and ac magnetic field
  - Liquid nitrogen
  - Monitor temperature
  - 100s and constant temperature >> “stable”
  - If temperature increases, cut current at 100K

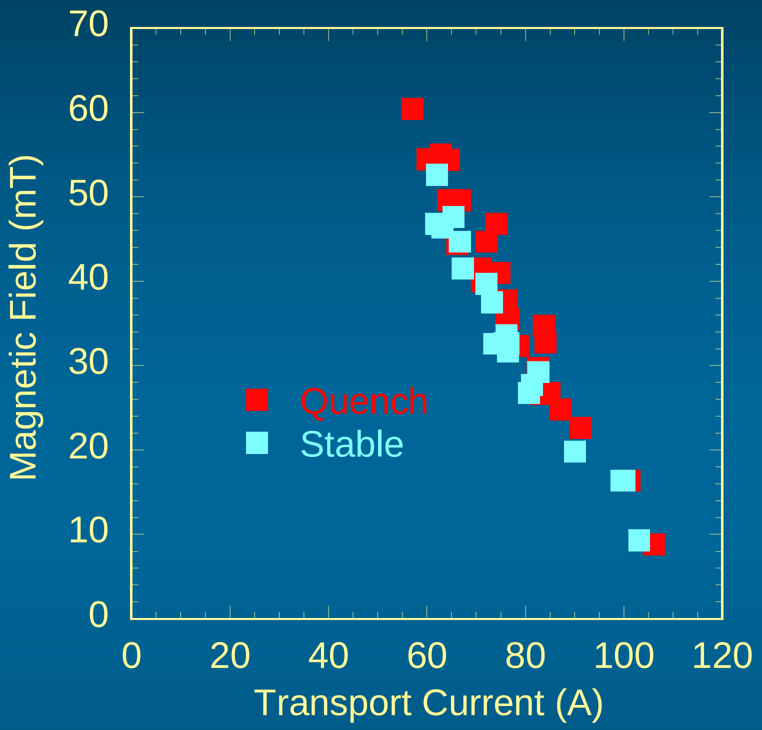


- Experiment
  - 60Hz field and current
  - 60A peak current
  - I_C= 110A



Stability boundary

- Well defined stability line
- Three data sets;
  - 5mm of frozen alcohol "thermal insulation"
  - <1mm alcohol
  - Exposed to liquid nitrogen
- Stability line is same
- Difficult to quench below 20mT
  - Recall "penetration" field



ac Losses: conclusions

- The losses in coated conductors are presently too high
  - This is a problem for economics and cooling
  - It's a bigger problem for quench stability
- Avoid quench by adding eg copper stabilizer, but losses go up
- Simply increasing J_C will not solve the problem
- Reducing the width and increasing J_C will help
- Filaments are not the solution, unless twisted
- No need to transpose filaments, if J_C is high enough

- What are the solutions?

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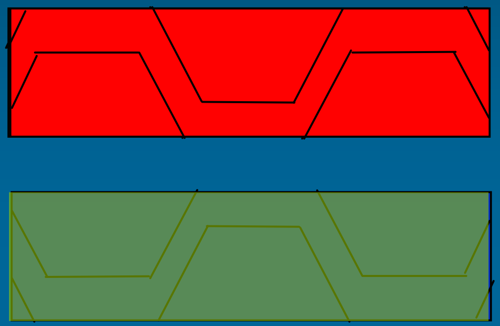
Ac Losses: Three possible solutions

- "Twisted" Filaments
  - Requires a double layer YBCO technology
  - Striated YBCO layers
  - Insulating interface
- Low aspect ratio conductor, "3D"
  - 1mm wide CC
  - 10 micron YBCO layer
  - $J_c > 0.1 MA/cm^2$
- High J_c, narrow conductor
  - 1mm wide
  - $J_c > 5 MA/cm^2$



Project Plans and Objectives FY2004

This project aimed to study aspects of the ac losses of BSCCO tapes and YBCO coated conductors.

1. Measure ac losses in BSCCO 2223 tapes in the 20-40K temperature regime.
2. Assemble predictive equations for the losses in this temperature range
3. Determine conductor temperature rises when exposed to large fluctuations in applied field (ie 1T increase in 1second).
4. Measure losses on various Coated Conductor samples with ac transport currents and ac magnetic fields.
5. Magnetic ac loss measurements of YBCO films in perpendicular fields
6. Measure of losses with fields at various angles to the conductor
7. Study conductor interaction (stacks, arrays) on ac losses.
8. Develop lower loss conductors
9. Study cryo-stabilization of coated conductors under ac conditions

Performance FY2004

- AC Losses has the potential to severely limit the application of CC.
- This year, and next, none of our goals are as important as understanding and reducing the ac losses.
- Plan evolved - losses in CC became our sole focus

Performance FY2004

1. Measure ac losses in BSCCO 2223 tapes in the 20-40K temperature regime.
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4. **Measure losses on various Coated Conductor samples with ac transport currents and ac magnetic fields.**
5. **Magnetic ac loss measurements of YBCO films in perpendicular fields**
6. Measure of losses with fields at various angles to the conductor
7. Study conductor interaction (stacks, arrays) on ac losses.
8. **Develop lower loss conductors**
9. **Study cryo-stabilization of coated conductors under ac conditions**

Plans and Goals FY 2005

1. Not to present this talk to you next year!
   - Present it in “wire session”
   - AC loss reduction a central part of coated conductor development
2. Develop and test conductor architecture
   - Capable of carrying 100A/cm width ac current in 100mT ac field without quenching (present limit is 10mT)
   - Capable of carrying 100A/cm width ac current in 10mT ac field with ac losses **TWO** orders of magnitude below present values.
3. Develop and test a conductor production technique (lengths > 10cm)
   - Capable of carrying 100A/cm width ac current in greater than 10mT ac field without quenching.
   - Capable of carrying 100A/cm width ac current in 10mT ac field with ac losses **ONE** order of magnitude below present values.
4. Priorities
   - High Jc, 1mm wide tapes ($Jc>3MA/cm^2$)
   - “3D” CC (1mm wide, 10um thick)
   - Double layer technology

Research Integration

- Coated conductor materials in collaboration with
  - LANL IBAD team
  - IGC-Superpower
- Air Force funded STTR Collaboration (Long Electromagnetic Industries)
- DARPA funded program
  - American Superconductor Corporation
  - Office of Naval Research